

MERRIMACK RIVER BASIN  
NORTH NASHUA RIVER  
LEOMINSTER , MASSACHUSETTS

**HYDROLOGIC ANALYSIS  
FOR  
MONOOSNOC BROOK  
FLOOD CONTROL**

WATER CONTROL BRANCH  
ENGINEERING DIVISION

DEPARTMENT OF THE ARMY  
NEW ENGLAND DIVISION, CORPS OF ENGINEERS  
WALTHAM, MASS.

OCTOBER 1976

MERRIMACK RIVER BASIN  
NORTH NASHUA RIVER WATERSHED  
MONOOSNOC BROOK FLOOD CONTROL  
LEOMINSTER, MASSACHUSETTS  
HYDROLOGIC ANALYSIS

| <u>Paragraph</u> | <u>Subject</u>         | <u>Page</u> |
|------------------|------------------------|-------------|
| 1.               | INTRODUCTION           | 1           |
| 2.               | WATERSHED DESCRIPTION  | 2           |
| 3.               | CLIMATOLOGY            | 2           |
| a.               | General                | 2           |
| b.               | Temperature            | 2           |
| c.               | Precipitation          | 3           |
| d.               | Snowfall               | 4           |
| e.               | Snow Cover             | 5           |
| 4.               | STREAMFLOW             | 5           |
| 5.               | FLOOD DEVELOPMENT      | 7           |
| a.               | General                | 7           |
| b.               | March 1936 Flood       | 7           |
| c.               | September 1938 Flood   | 7           |
| d.               | October 1955 Flood     | 9           |
| 6.               | FLOOD FREQUENCIES      | 9           |
| 7.               | STANDARD PROJECT FLOOD | 9           |
| a.               | General                | 9           |
| b.               | Rainfall               | 10          |
| c.               | Unit Hydrographs       | 10          |
| d.               | Standard Project Flood | 10          |
| 8.               | FLOOD PROFILES         | 12          |
| 9.               | MONOOSNOC BROOK BYPASS | 12          |
| a.               | General                | 12          |
| b.               | Design Capacity        | 12          |
| c.               | Required Assurances    | 13          |
| d.               | Bypass Tunnel          | 13          |
| e.               | Bypass Inlet           | 13          |
| f.               | Bypass Outlet          | 14          |
| g.               | Effects of Bypass      | 14          |

## LIST OF TABLES

| <u>Table</u> | <u>Title</u>  | <u>Page</u> |
|--------------|---|-------------|
| 1            | Monthly Temperatures at Fitchburg,<br>Massachusetts                         | 3           |
| 2            | Monthly Precipitation at Fitchburg,<br>Massachusetts                        | 4           |
| 3            | Snowfall Data at Fitchburg, Massachusetts                                   | 4           |
| 4            | Water Equivalent In Snow Cover, Millers<br>River Watershed                  | 5           |
| 5            | Peak Discharge, USGS Gage, North Nashua<br>River, Leominster, Massachusetts | 6           |
| 6            | Monthly Runoff, North Nashua River  | 6           |
| 7            | Maximum Rainfall - Duration Data  | 8           |
| 8            | Standard Project Storm Rainfall   | 11          |
| 9            | Effects of Monoosnoc Brook Bypass   | 15          |

## LIST OF PLATES

| <u>Plate</u> | <u>Title</u>                            |
|--------------|---|
| 1            | Watershed Map                           |
| 2            | March 1936 Flood Analysis               |
| 3            | Discharge Frequency                     |
| 4            | One Hour Unit-Graph                     |
| 5            | Notown Reservoir Standard Project Flood |
| 6            | Rockwell Pond Standard Project Flood    |
| 7            | Monoosnoc Brook Standard Project Flood  |
| 8            | Flood Profiles                          |
| 9            | Standard Project Flood Limits           |
| 10           | Monoosnoc Brook Bypass Plan & Profile   |
| 11           | Monoosnoc Brook Bypass Inlet            |
| 12           | Monoosnoc Brook Bypass Outlet           |
| 13           | Monoosnoc Brook Bypass Plans & Sections |
| 14           | Rockwell Pond Discharge Ratings         |

MERRIMACK RIVER BASIN  
NORTH NASHUA RIVER WATERSHED  
MONOOSNOC BROOK FLOOD CONTROL  
LEOMINSTER, MASSACHUSETTS  
HYDROLOGIC ANALYSIS

## 1. INTRODUCTION

This report presents the hydrologic analysis pertinent to the revised flood control plan for Monoosnoc Brook in Leominster, Massachusetts. Included are sections on watershed description, climatology, flood history, flood frequencies, standard project flood development, and hydrologic features of the proposed improvements.

Monoosnoc Brook is a tributary to the North Nashua River and was included in studies reported in "Water Resource Development Plan, North Nashua River Basin", dated January 1965. At that time a flood control reservoir was recommended on Monoosnoc Brook, together with some channel improvements in combination with a proposed urban renewal project. This plan was subsequently authorized by Congress. However, escalating real estate costs and development in the reservoir site plus the rejection of the originally planned urban renewal project by the city council resulted in the city requesting a flood control restudy of the brook in 1972. The restudy was funded by the Public Works Appropriation Act of 1975 (Public Law 93-393, dated 28 August 1974) under the general investigations provisions.

The current restudy has determined that the reservoir is no longer feasible but that a deep rock tunnel bypass of the brook through the center of Leominster is a practical alternative. Therefore, the presently recommended plan for flood control on Monoosnoc Brook in the city of Leominster consists of a 12-foot diameter tunnel extending from Rockwell Pond, a distance of 3,200 feet to an outlet downstream of Water Street Dam.

## 2. WATERSHED DESCRIPTION

Monoosnoc Brook originates at Rocky Pond in the hills west of the city of Leominster and flows in a general easterly direction for 8.7 miles through the business center of Leominster to its confluence with the North Nashua River about nine miles upstream of the junction of the North Nashua and Nashua Rivers. The Nashua River in turn enters the Merrimack River in Nashua, New Hampshire. A watershed map of Monoosnoc Brook is shown on plate 1.

Monoosnoc Brook has a total drainage area of 11.2 square miles. Flood runoff from the upper 4.7 square miles of the watershed is largely controlled by surcharge storage in Notown reservoir, a large domestic water supply lake. The intervening 5.7 square miles between Notown reservoir and the city of Leominster is very hilly and conducive to rapid runoff. The remaining 0.8 square mile of watershed, mostly within the city of Leominster, is flatter in slope but quite heavily urbanized. New development taking place in the watershed is mostly upstream of Leominster and along Route 2, a limited access highway passing through the northern portion of the watershed.

Further discussion of the Monoosnoc Brook watershed and the larger North Nashua basin is contained in the 1965 "Water Resources Development Plan, North Nashua River Basin".

## 3. CLIMATOLOGY

a. General. The Monoosnoc Brook watershed has a variable climate and frequently experiences periods of heavy precipitation produced by local thunderstorms and larger weather systems of tropical and extratropical origin. The basin lies in the path of the prevailing "westerlies" which traverse the country in an easterly or northeasterly direction and produce frequent weather changes. Temperature extremes within the basin range from summer-time highs of about 100° Fahrenheit to sub-zero temperatures in the minus teens occurring for short periods in the winter.

b. Temperature. The mean annual temperature in the North Nashua River watershed is about 48° Fahrenheit. Recorded temperature extremes at representative stations within or adjacent to the watershed have varied from a maximum of 105° F. at Fitchburg

to a minimum of -22° F. at Clinton, Massachusetts. Freezing temperatures may be expected from the latter part of September until late in April. Table 1 shows the mean, maximum and minimum monthly and annual temperatures at Fitchburg for 89 years of record through 1975.

TABLE 1  
MONTHLY TEMPERATURES AT  
FITCHBURG, MASSACHUSETTS  
(Degrees Fahrenheit)

| <u>Month</u> | <u>Average</u> | <u>Maximum</u> | <u>Minimum</u> |
|--------------|----------------|----------------|----------------|
| January      | 24.8           | 68             | -21            |
| February     | 25.0           | 68             | -21            |
| March        | 34.5           | 86             | -8             |
| April        | 46.0           | 92             | 6              |
| May          | 57.7           | 97             | 26             |
| June         | 66.4           | 100            | 35             |
| July         | 71.6           | 103            | 40             |
| August       | 69.3           | 105            | 35             |
| September    | 62.1           | 101            | 27             |
| October      | 51.3           | 91             | 16             |
| November     | 39.9           | 81             | -2             |
| December     | 28.6           | 71             | -16            |
| Annual       | 48.1           |                |                |

c. Precipitation. The average annual precipitation over the North Nashua River basin is approximately 43 inches, uniformly distributed throughout the year. The maximum and minimum annual precipitation at Fitchburg is 60.23 (1954) and 27.45 (1883) inches, respectively. Table 2 shows the mean, maximum and minimum monthly and annual precipitation at Fitchburg for 111 years of record through 1975.

TABLE 2

MONTHLY PRECIPITATION AT  
FITCHBURG, MASSACHUSETTS  
(In Inches)

| <u>Month</u> | <u>Mean</u> | <u>Maximum</u> | <u>Minimum</u> |
|--------------|-------------|----------------|----------------|
| January      | 3.44        | 7.78           | 0.84           |
| February     | 3.28        | 8.33           | 0.34           |
| March        | 3.67        | 12.15          | Trace          |
| April        | 3.42        | 9.91           | 0.57           |
| May          | 3.57        | 8.25           | 0.57           |
| June         | 3.66        | 11.56          | 0.09           |
| July         | 3.67        | 12.68          | 0.46           |
| August       | 3.66        | 10.72          | 0.17           |
| September    | 3.64        | 14.04          | 0.19           |
| October      | 3.43        | 13.01          | Trace          |
| November     | 3.84        | 7.79           | 0.38           |
| December     | 3.51        | 9.33           | 0.58           |
| Annual       | 32.77       | 60.23          | 27.45          |

d. Snowfall. The annual snowfall in the basin averages about 60 inches at Fitchburg located at about elevation 400 feet msl. Table 3 shows the mean monthly and annual snowfall at Fitchburg for 90 years of record through 1975.

TABLE 3

SNOWFALL DATA AT  
FITCHBURG, MASSACHUSETTS  
(Depth in Inches)

| <u>Month</u> | <u>Mean</u> |
|--------------|-------------|
| January      | 15.6        |
| February     | 17.6        |
| March        | 11.3        |
| April        | 2.5         |
| May          | Trace       |
| June         | -           |
| July         | -           |
| August       | -           |
| September    | -           |
| October      | Trace       |
| November     | 3.5         |
| December     | 11.7        |
| Annual       | 62.2        |

e. Snow Cover. Snow surveys have been taken by the Corps of Engineers, in or adjacent to, the North Nashua River watershed since 1950. These surveys indicate that the water content of the snow normally reaches a maximum about mid-March. The mean, maximum, and minimum water content of the snow cover measured in the nearby Millers River watershed for 27 years of record through 1976 is shown in table 4.

TABLE 4

WATER EQUIVALENT IN SNOW COVER  
MILLERS RIVER WATERSHED  
1950-1976  
(Inches)

|             | <u>Mean</u> | <u>Maximum</u> | <u>Minimum</u> |
|-------------|-------------|----------------|----------------|
| 1 February  | 2.1         | 4.2            | 0.3            |
| 15 February | 2.7         | 5.6            | 0.0            |
| 1 March     | 3.1         | 7.6            | 0.0            |
| 15 March    | 3.2         | 7.7            | 0.0            |
| 1 April     | 2.0         | 8.2            | 0.0            |
| 15 April    | 0.3         | 4.9            | 0.0            |

#### 4. STREAMFLOW

There are no streamflow records for Monoosnoc Brook; however, average annual flow is believed in the order of 15 cfs based on records of other streams in the region. Minimum flows approach zero quite frequently during the summer months and the maximum flow on the stream occurred in March 1936 when the peak approximated 2,000 cfs based on high watermarks at the Water Street dam (10.8 square miles) and computation of flow over the crest.

There is a U.S. Geological Survey gaging station on the North Nashua River at Leominster. Drainage area above this gage is 107 square miles and includes Monoosnoc Brook. Average annual runoff for 39 years of record through water year 1974 has varied from 307 cfs in 1956 to 81.2 in 1965, with a mean of 192.8. Records at the gage indicate that there have been several periods of sustained low flow in the North Nashua River. The longest and most severe drought, 1961-1966, resulted in a cumulative runoff deficiency of 31.75 inches which is 135 percent of the average annual runoff (24.6 inches) at the Leominster gage. The maximum and minimum instantaneous flows recorded at the gage were 16,300 cfs on 18 March 1936 and 11 cfs on 29 August 1948, respectively. Table 5 lists pertinent data for the five largest events of record at the gage, while table 6 is a summary of the mean, maximum, and

minimum monthly and annual runoff in cfs and inches for the period of record at the Leominster USGS gage.

TABLE 5

PEAK DISCHARGE  
USGS GAGE, NORTH NASHUA RIVER  
LEOMINSTER, MASSACHUSETTS

| <u>Date</u> | <u>Average<br/>Rainfall<br/>(inches)</u> | <u>Peak<br/>Discharge</u> |              | <u>Runoff<br/>(inches)</u> |
|-------------|--|---------------------------|--------------|----------------------------|
|             |  | <u>(cfs)</u>              | <u>(csm)</u> |                            |
| 18 Mar 1936 | 5.5                                      | 16,300                    | 152          | 4.0                        |
| 21 Sep 1938 | 7.5                                      | 10,300                    | 96           | 4.7                        |
| 15 Oct 1955 | 7.5                                      | 8,870                     | 83           | 5.0                        |
| 25 Jun 1944 | 5.5                                      | 8,100                     | 76           | -                          |
| 12 Mar 1936 | 3.0                                      | 5,500                     | 51           | -                          |

TABLE 6

MONTHLY RUNOFF  
NORTH NASHUA RIVER  
DA = 107 square miles  
Oct 1935 - Sep 1974

| <u>Month</u> | <u>Average</u> |               | <u>Maximum</u> |               | <u>Minimum</u> |               |
|--------------|----------------|---------------|----------------|---------------|----------------|---------------|
|              | <u>CFS</u>     | <u>Inches</u> | <u>CFS</u>     | <u>Inches</u> | <u>CFS</u>     | <u>Inches</u> |
| January      | 205.2          | 2.2           | 465            | 5.1           | 50.9           | 0.6           |
| February     | 215.7          | 2.1           | 534            | 5.2           | 88.8           | 0.9           |
| March        | 372.7          | 4.0           | 1289           | 14.0          | 140.0          | 1.5           |
| April        | 422.5          | 4.4           | 868            | 9.1           | 154.0          | 1.6           |
| May          | 292.7          | 2.6           | 450            | 4.9           | 85.4           | 0.9           |
| June         | 155.5          | 1.6           | 393            | 4.3           | 64.3           | 0.7           |
| July         | 91.1           | 1.0           | 392            | 4.3           | 42.9           | 0.5           |
| August       | 75.1           | 0.8           | 286            | 3.1           | 38.1           | 0.4           |
| September    | 90.6           | 0.9           | 595            | 6.3           | 38.9           | 0.4           |
| October      | 95.8           | 1.0           | 606            | 6.6           | 39.4           | 0.4           |
| November     | 155.6          | 1.6           | 485            | 5.1           | 44.4           | 0.5           |
| December     | 190.8          | 2.0           | 429            | 4.6           | 58.6           | 0.6           |
| Water Year   | 192.8          | 24.6          | 307*           | 39.4          | 81.2**         | 10.4          |

\*1950

\*\*1965

## 5. FLOOD DEVELOPMENT

a. General. The 11.2 square mile Monoosnoc Brook watershed may be divided into two subareas with respect to flood development: (1) the 4.7 square mile headwater area controlled by Notown Reservoir, and (2) the 6.5 square mile area below Notown Dam. The reservoir is normally filled to spillway crest, forming a 250-acre pool; however, the surcharge storage above spillway crest effectively reduces and delays peak flows originating in the upper watershed. Runoff from the area below the reservoir is uncontrolled and its hilly topography is conducive to rapid rainfall runoff. Runoff from the portion of the watershed downstream of the reservoir is the main producer of floods in Leominster.

b. March 1936 Flood. The greatest known flood on Monoosnoc Brook occurred as the result of the second storm during March 1936. Intermittent periods of moderate to heavy rainfall during the month, combined with considerable snowmelt, produced two floods. The first rise, occurring on the 12th, was largely the result of runoff from melting snow with some contribution from moderate rainfall which averaged about three inches over the basin during the period from 9-13 March. A second storm period, between the 16th and 19th, produced the record flood on Monoosnoc Brook on the 18th. This second flood peak resulted from intense rainfall, which averaged about 5.5 inches, with only minor contribution from snowmelt. The resulting peak flow on Monoosnoc Brook was about 2,000 cfs and plate 2 graphically illustrates the development of the computed 1936 flood hydrograph and its contribution to the North Nashua River at Leominster. A comparison of associated 1936 rainfall amounts are listed in table 7.

c. September 1938 Flood. Another flood producing event occurred as a result of rainfall associated with the September 1938 hurricane that passed up the Connecticut River Valley. The Monoosnoc Brook watershed just narrowly missed the brunt of this storm with rainfall amounts of 14 inches occurring a short distance to the west. However, rainfall averaged about 7 inches on 18-21 September in the basin with about 4 inches falling in a 24-hour period on the 20th. The peak resulting flow on Monoosnoc Brook has been estimated at about 1,400 cfs based on rainfall-runoff computations. September 1938 rainfall amounts as recorded at Worcester, Massachusetts, compared with other storms, are listed in table 7.

TABLE 7

MAXIMUM RAINFALL - DURATION DATA  
(In Inches)

| <u>Storm</u>                     | <u>1 hr.</u> | <u>2 hr.</u> | <u>3 hr.</u> | <u>6 hr.</u> | <u>12 hr.</u> | <u>24 hr.</u> |
|----------------------------------|--------------|--------------|--------------|--------------|---------------|---------------|
| 10-year frequency                | 1.8          | 2.3          | 2.6          | 3.3          | 3.9           | 4.7           |
| 100-year frequency               | 2.6          | 3.4          | 3.7          | 4.6          | 5.4           | 6.3           |
| Standard Project                 | 3.3          | 4.6          | 5.8          | 8.7          | 10.2          | 11.9          |
| March 1936<br>(at Worcester)     | 0.8          | 1.0          | 1.4          | 2.3          | 4.1           | 5.3           |
| September 1938<br>(at Worcester) | 0.7          | 1.0          | 1.3          | 2.1          | 2.6           | 3.8           |
| October 1955<br>(at Sterling)    | 0.5          | 0.8          | 1.0          | 1.7          | 3.1           | 4.6           |

d. October 1955 Flood. The Monoosnoc Brook watershed escaped the widespread torrential hurricane rainfalls of August 1955 but did experience flood producing rainfall in October 1955. The October storm resulted from the interaction of a west to east frontal weather system with a coastal low pressure system moving northward. Rainfall in the watershed amounted to about 5 inches in 24 hours on the 15th based on rainfall records at Sterling, Massachusetts.

## 6. FLOOD FREQUENCIES

An adopted peak discharge frequency curve for Monoosnoc Brook is shown on plate 3. The curve was developed by relating the computed frequency statistics of the flow records for the North Nashua River at Leominster to Monoosnoc Brook through comparison of common flood events at the two locations. Statistical analysis was made in accordance with Water Resources Bulletin 17 and consideration was given to: (a) regional frequency analyses, i.e., analysis of the North Nashua record, (b) the estimated magnitude and plotting position of the three historic floods on Monoosnoc Brook and, (c) the computed 100- and 10-year storm runoff based on a rainfall-unit hydrograph analysis.

The computed mean log, standard deviation and adopted skew for the North Nashua River at Leominster, with a drainage area of 107 square miles was 3.3634, 0.3033, and 0.8, respectively. The adopted parameters for Monoosnoc Brook with a drainage area of 11.2 square miles was: mean log = 2.669, standard deviation = 0.2924, and adopted skew = 0.50. It was considered that the adopted frequency curve was sufficiently high to be representative of runoff conditions under present and near future levels of development in the watershed.

## 7. STANDARD PROJECT FLOOD

a. General. A standard project flood (SPF) was developed for Monoosnoc Brook by applying standard project rainfall to synthetically developed unit hydrographs for various subwatersheds and the resulting component hydrographs were then routed and combined at selected index points. The SPF represents the flood discharge that may be expected from the most severe combination of meteorologic and hydrologic conditions that are considered reasonably characteristic of the region, excluding extremely rare combinations.

b. Rainfall. Standard project storm rainfall was determined in accordance with Civil Engineer Bulletin 52-8 and EM 1110-2-1411. The 24-hour index rainfall for 200 square miles was 10.0 inches. This amount was increased 19 percent for the 11.2 square mile Monoosnoc watershed, resulting in an adjusted index rainfall of 11.9 inches. Losses were assumed to be 0.1 inch per hour and the resulting 24-hour rainfall excess was 9.5 inches. Hourly rainfall amounts are listed in table 8.

c. Unit Hydrographs. A synthetic 1-hour unit hydrograph was developed for the 6.5 square mile Monoosnoc Brook watershed downstream of Notown Reservoir and is shown on plate 4. The adopted unit graph had a peak of 506 cfs, equivalent to 78 cfs per square mile, and a lag time of 4.5 hours. Snyder's coefficients used in developing the unit graph and other pertinent data are listed on plate 4.

The unit graph was tested by determining the degree to which the 1936 flood peak could be reproduced. Representative runoff hydrographs for Notown Reservoir were first computed and then routed through surcharge storage to determine outflow. The outflow was then routed downstream and combined with the lower watershed runoff to establish the total 1936 flood hydrograph. Development of the 1936 flood is graphically illustrated on plate 2.

d. Standard Project Flood. The standard project flood for Monoosnoc Brook was developed as follows: (1) the standard project inflow to Notown Reservoir was computed and routed through surcharge storage, (2) the outflow was lagged to Rockwell Pond and combined with the computed runoff from the intervening 5.7 square miles of watershed and (3) the Rockwell Pond hydrograph was lagged to the mouth of the brook and combined with the local runoff from the 0.8 square mile of urban watershed in Leominster. The resulting peak discharges at Notown Reservoir, Rockwell Pond and the mouth of the brook were 1,410, 4,000 and 4,600 cfs, respectively. The component hydrographs at Notown Reservoir Rockwell Pond and the mouth of the brook are shown on plates 5, 6 and 7.

Inflow to Notown Reservoir had a peak of 2,750 cfs. After routing through surcharge storage the peak outflow was 1,410 cfs, and was delayed five hours after time of peak inflow. Although the peak outflow from Notown Reservoir was 1,410 cfs, due to desynchronization, it is noted that its contribution to the peak downstream discharge was only 400 cfs.

TABLE 8

STANDARD PROJECT  
STORM RAINFALL

| <u>Time</u><br><u>(hrs)</u> | <u>Rainfall</u><br><u>(inches)</u> | <u>Loss</u><br><u>(inches)</u> | <u>Excess</u><br><u>(inches)</u> |
|-----------------------------|------------------------------------|--------------------------------|----------------------------------|
| 1                           | 0.2                                | 0.1                            | 0.1                              |
| 2                           | 0.2                                | 0.1                            | 0.1                              |
| 3                           | 0.2                                | 0.1                            | 0.1                              |
| 4                           | 0.2                                | 0.1                            | 0.1                              |
| 5                           | 0.3                                | 0.1                            | 0.2                              |
| 6                           | 0.3                                | 0.1                            | 0.2                              |
| 7                           | 0.9                                | 0.1                            | 0.8                              |
| 8                           | 1.2                                | 0.1                            | 1.1                              |
| 9                           | 3.3                                | 0.1                            | 3.2                              |
| 10                          | 1.3                                | 0.1                            | 1.2                              |
| 11                          | 1.0                                | 0.1                            | 0.9                              |
| 12                          | 0.9                                | 0.1                            | 0.8                              |
| 13                          | 0.3                                | 0.1                            | 0.2                              |
| 14                          | 0.2                                | 0.1                            | 0.1                              |
| 15                          | 0.2                                | 0.1                            | 0.1                              |
| 16                          | 0.2                                | 0.1                            | 0.1                              |
| 17                          | 0.2                                | 0.1                            | 0.1                              |
| 18                          | 0.2                                | 0.1                            | 0.1                              |
| 19                          | 0.1                                | 0.1                            | 0.0                              |
| 20                          | 0.1                                | 0.1                            | 0.0                              |
| 21                          | 0.1                                | 0.1                            | 0.0                              |
| 22                          | 0.1                                | 0.1                            | 0.0                              |
| 23                          | 0.1                                | 0.1                            | 0.0                              |
| 24                          | <u>0.1</u>                         | <u>0.1</u>                     | <u>0.0</u>                       |
|                             | 11.9                               | 2.4                            | 9.5                              |

## 8. FLOOD PROFILES

Monoosnoc Brook flood profiles were computed utilizing the computer program, HEC-2, developed by the Hydrologic Engineering Center in Davis, California. Cross section data was taken from recent Corps of Engineers surveys from the mouth upstream to Water Street dam. From the dam upstream to Rockwell Pond, cross section information was taken from a flood control plan completed for the city of Leominster by Mr. William P. Ray, C.E., in 1938. The 1938 data was verified by field investigation. Backwater computations were made for both natural and modified conditions using a Manning's "n" of 0.035 for the channel and 0.06 for over-bank areas. Assumed contraction and expansion loss coefficients for all bridges were 0.3 and 0.5, respectively. The computed standard project flood profile, both natural and as modified by the proposed bypass tunnel, is shown on plate 8. Limits of flooding are shown on plate 9.

## 9. MONOOSNOC BROOK BYPASS

a. General. The proposed deep rock tunnel will serve to bypass floodflows from the existing Rockwell Pond, located just upstream of the Leominster business district, to a point approximately 900 feet downstream of the Water Street dam, a distance of 3,200 feet.

Hydrologic engineering features of the various components of the proposed diversion are shown on plates 10 through 13 and discussed in the following paragraphs. Hydraulic analyses during plan formulation were general in scope. More detailed analyses, probably including model studies of some of the more complex hydraulic structures, will be required in final design.

b. Design Capacity. The tunnel bypass, in combination with the existing channel capacity, will be designed to safely convey the standard project flood through the urban center of Leominster. The SPF discharge at Rockwell Pond is 4,000 cfs, of which 3,400 will be conveyed in the bypass tunnel while the remaining 600 cfs will be discharged into the existing channel. Designing to the level of the SPF was found feasible in project formulation studies and was considered advisable due to the high damage potential in the city. It is noted that in the event of flows greater than the SPF, the bypass will still serve to reduce flows by an amount equal to its capacity of approximately 3,500 cfs.

c. Required Assurances. The ability of the proposed improvements to safely convey the SPF will be dependent on the maintenance of both the integrity of the existing Rockwell Pond dam and the existing safe channel capacity through Leominster. Therefore, as part of local assurances it will be necessary to stipulate that the dam and channel be appropriately maintained.

d. Bypass Tunnel. The 12-foot diameter tunnel will be concrete-lined and approximately 3,200 feet in length. The invert of the tunnel at the upstream end will be 308 feet msl and will slope at 0.0137 ft/ft to elevation 264 feet msl at the outlet. With the design discharge of 3,400 cfs, the velocity of flow in the tunnel will be about 30 feet per second. The hydraulic capacity of the tunnel was computed using a Manning's "n" of 0.014. A profile of the tunnel including the design hydraulic gradient are shown on plate 10.

e. Bypass Inlet. The inlet to the tunnel, shown on plate 11, is of the "morning glory" type atop a 14-foot diameter vertical shaft. The 14-foot diameter transitions to 12 feet diameter before entering the tunnel. The transition starts at elevation 348 feet msl, which is the hydraulic gradient of the tunnel for a flow of only about 1,400 cfs. The larger 14-foot shaft was selected to insure free aeration of the flow, thereby minimizing the possibility of "burping" or "gulping" as has been experienced with minimum sized morning glory spillways. The inlet will also be equipped with "splitter walls" to minimize potential vortex action. Trash racks are provided for the collection of debris and personal safety. The inlet crest was shaped for a design "Hs" of 4.8 feet, thereby insuring complete support of the nappe up to the actual design head of 3.5 feet. Crest shape data was taken from: "Design of Small Dams", U.S. Department of Interior, Bureau of Reclamation, 1960 edition.

Operation of the bypass for flood control will be automatic through the proper selection of elevation and length of the two overflow weirs. The level at Rockwell Pond is presently maintained by a granite block dam about 13 feet high with crest elevation at 415.7 feet msl and an effective length of about 68 feet. With the proposed plan of improvement, the effective length of the existing spillway will be reduced to 22.5 feet while maintaining the same crest elevation. Elevation of the bypass crest will be one foot higher at elevation 416.7 feet msl and will have an effective crest length of 138 feet. The original dam crest

being one foot lower than the bypass will allow passage of normal riverflows downstream through Leominster in the old Monoosnoc Brook channel. During flood periods the lip of the morning glory inlet will be the hydraulic control for bypass flows up to approximately 3,400 cfs, with a required head pool elevation at the inlet of about 420.2 feet msl. With flows greater than 3,400 cfs the inlet will become submerged by tunnel backwater and the hydraulic control will switch to the tunnel outlet. With the head pool at elevation 420.2 feet msl, the system will be capable of discharging the SPF discharge of 4,000 cfs with 3,400 going through the bypass and 600 being discharged into the existing Monoosnoc channel.

Outlet rating curves for Rockwell Pond are shown on plate 14.

f. Bypass Outlet. The outlet of the bypass tunnel will consist of a 12-foot diameter vertical shaft transitioning to a 32-foot wide horizontal apron with an invert elevation at elevation 320 feet msl. A plan and profile of the outlet is shown on plate 13.

An apron of riprap will be placed at the outlet exit to prevent excessive scour. With a design flow of 3,400 cfs in the bypass, the velocity in the vertical shaft will be approximately 30 feet per second. Water level at the top of the shaft would rise to near the energy gradient of 334 feet msl and then drop to about 332 feet msl as it passes over the apron end sill. Velocities of flows exiting the outlet structure will be about 8 feet per second. Design tailwater at the outlet structure is elevation 333 feet msl based on backwater computations.

A breakaway fence will be placed across the outlet to prevent a person from unknowingly entering the outlet.

g. Effects of Bypass. The effects of the proposed bypass tunnel on flows and stages as computed for the standard project and March 1936 floods is summarized in table 9.

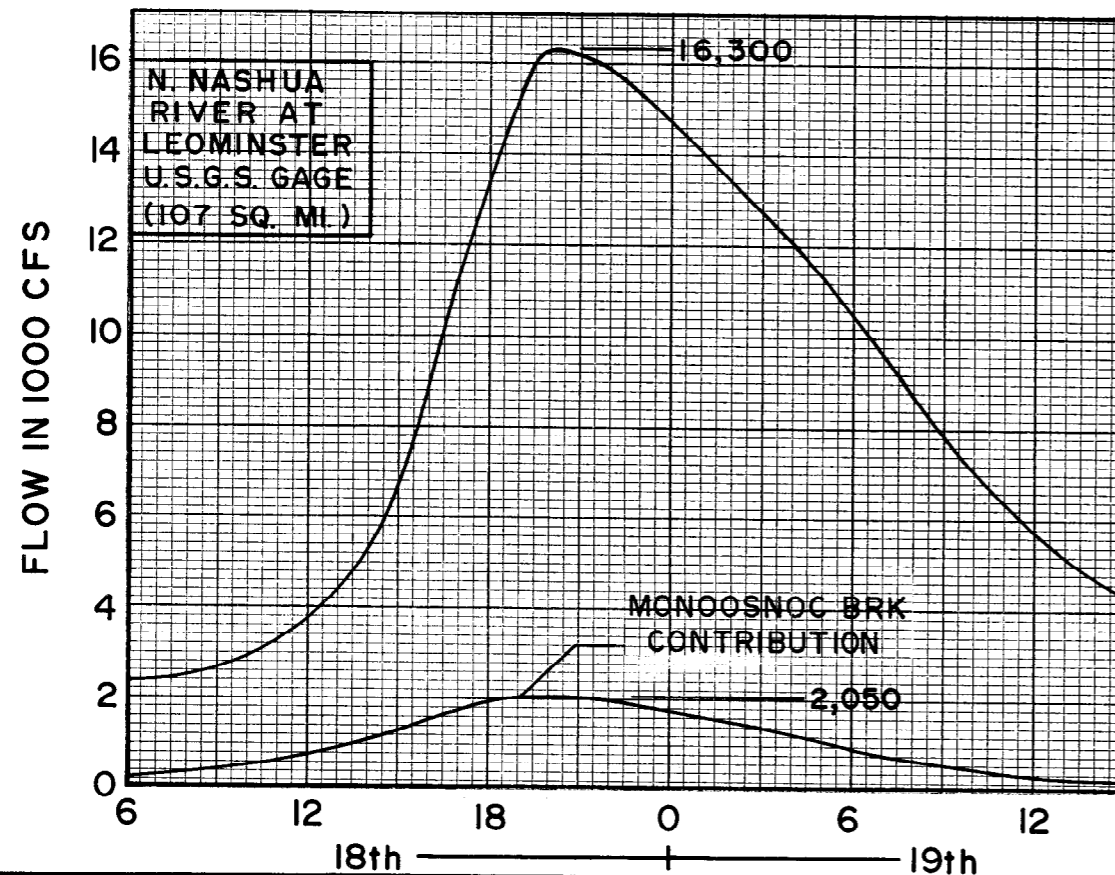
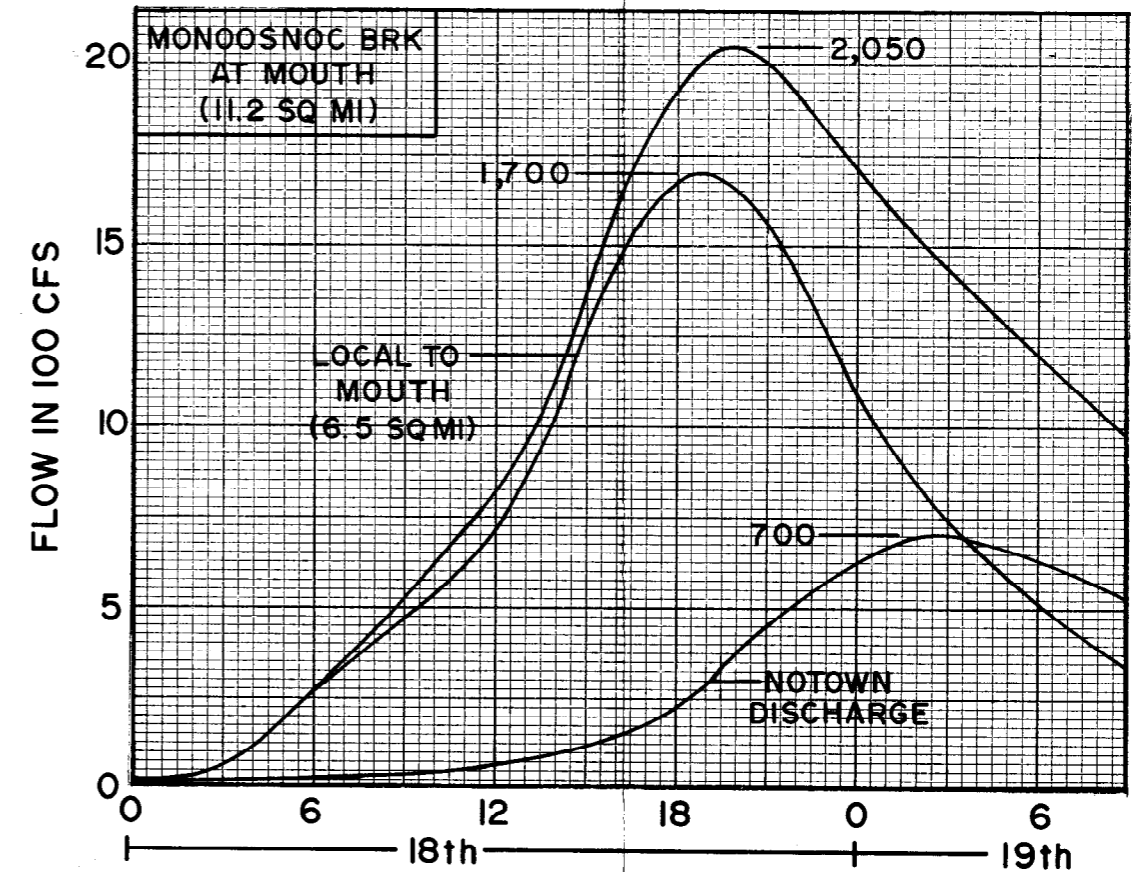
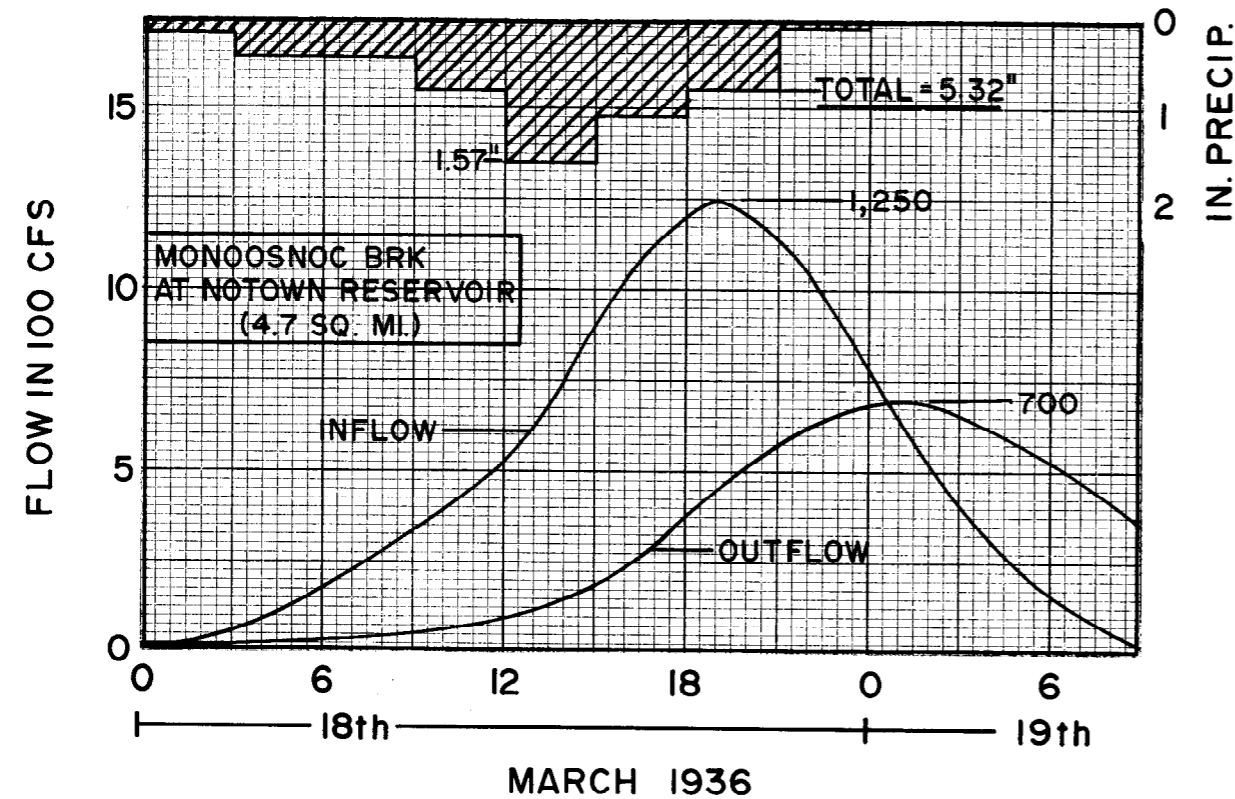
Due to the shorter time of travel of flows from Rockwell Pond there will be minor increases in flows downstream of the tunnel outlet, generally considered less than 5 percent. The increase in stage for a standard project flood would be less than 5 inches. The tunnel will not affect the total volume of runoff and due to the natural desynchronization of flows on Monoosnoc Brook and the main stem of the North Nashua River, it is considered the proposed diversion would not have any measurable effect on stages on the North Nashua River below the mouth of Monoosnoc Brook.

TABLE 9

EFFECTS OF MONOOSNOC BROOK BYPASS

| <u>Location</u>  | Drainage<br>Area<br>(ac/ft) | Standard Project Flood |              |          |              | 1936 Flood |              |          |              |
|------------------|-----------------------------|------------------------|--------------|----------|--------------|------------|--------------|----------|--------------|
|                  |                             | Natural                |              | Modified |              | Natural    |              | Modified |              |
|                  |                             | <u>Q</u>               | <u>Elev.</u> | <u>Q</u> | <u>Elev.</u> | <u>Q</u>   | <u>Elev.</u> | <u>Q</u> | <u>Elev.</u> |
| Notown Reservoir | 4.7                         | 1410                   | -            | 1410     | -            | 700        | -            | 700      | -            |
| Rockwell Pond    | 10.4                        | 4000                   | 422.4        | 600      | 420.2        | 1885       | 419.7        | 360      | 418.5        |
| Adams Street     | 10.6                        | 4150                   | 403.8        | 800      | 394.2        | 1940       | 399.8        | 410      | 391.5        |
| Mechanic Street  | 10.6                        | 4150                   | 395.0        | 800      | 389.3        | 1940       | 391.9        | 410      | 387.8        |
| Water Street Dam | 10.8                        | 4300                   | 355.4        | 1000     | 351.5        | 1990       | 353.0        | 480      | 350.5        |
| Monoosnoc Brook  | 11.2                        | 4600                   | -            | 4800     | -            | 2050       | -            | 2100     | -            |

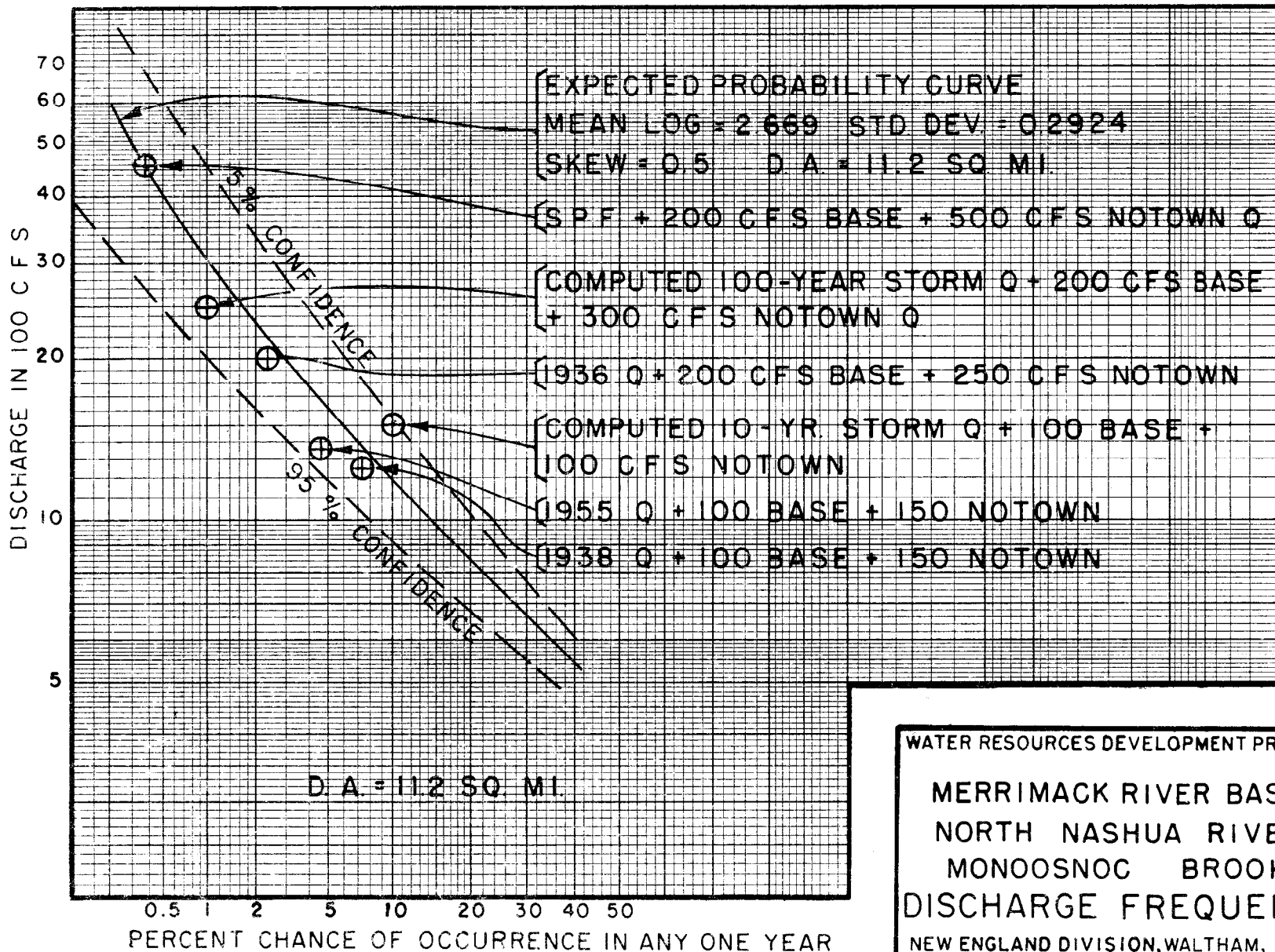




### NOTES

1. ALL HYDROGRAPHS ON MONOOSNOC BROOK ARE COMPUTED BASED ON ADOPTED UNIT HYDROGRAPHS AND WORCESTER, MASSACHUSETTS, HOURLY RAIN FALL.
2. LOSSES ARE ASSUMED NEGLIGIBLE DUE TO ACCOMPANYING SNOWMELT AND SATURATED SOIL CONDITIONS.
3. PEAK FLOW WAS SUBSTANTIATED BASED ON HIGH WATER MARK AT WATER ST. DAM.

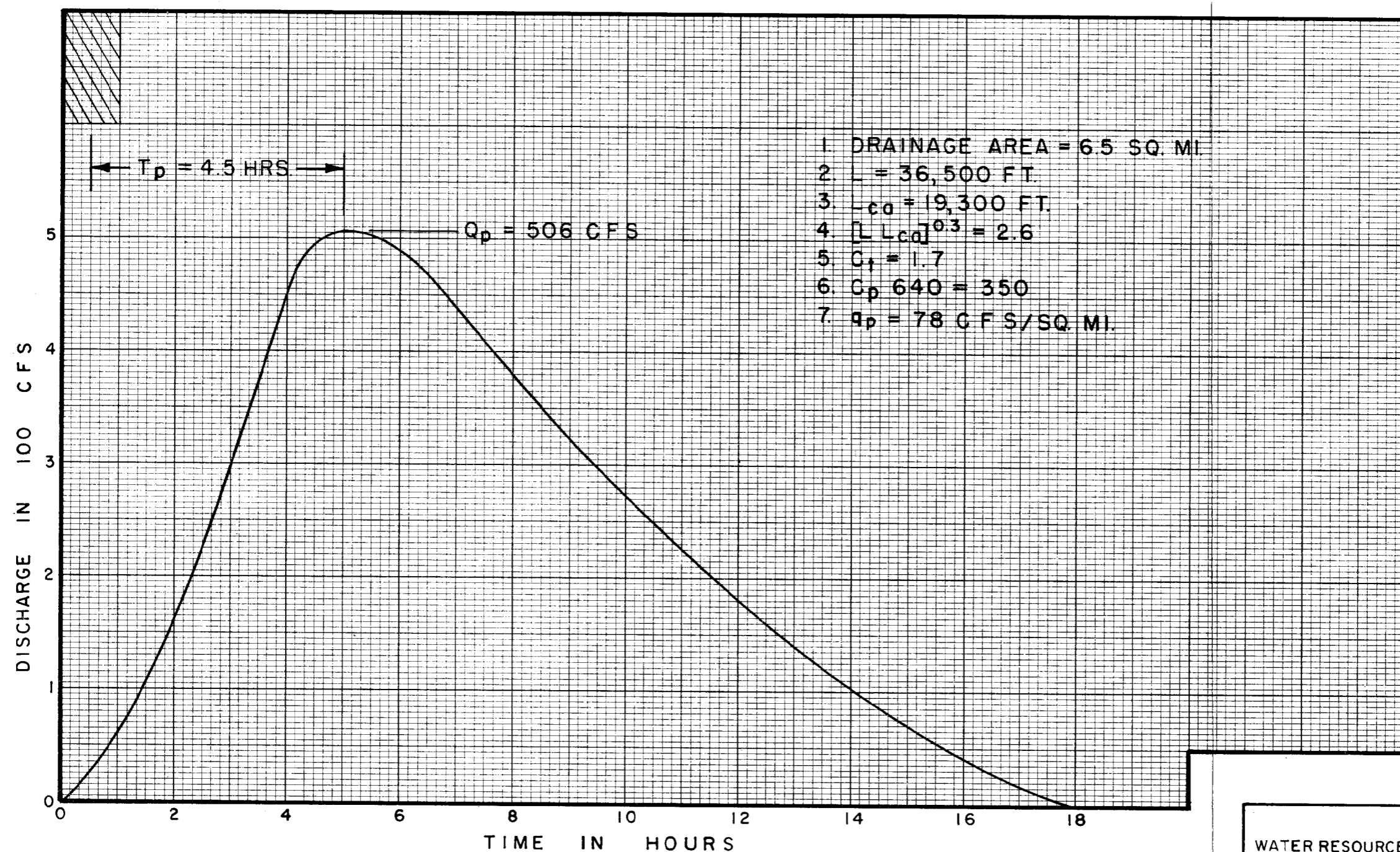
WATER RESOURCES DEVELOPMENT PROJECT  
MERRIMACK RIVER BASIN  
NORTH NASHUA RIVER  
MONOOSNOC BROOK  
MARCH 1936 FLOOD ANALYSIS  
NEW ENGLAND DIVISION, WALTHAM, MASS.  
OCTOBER 1976



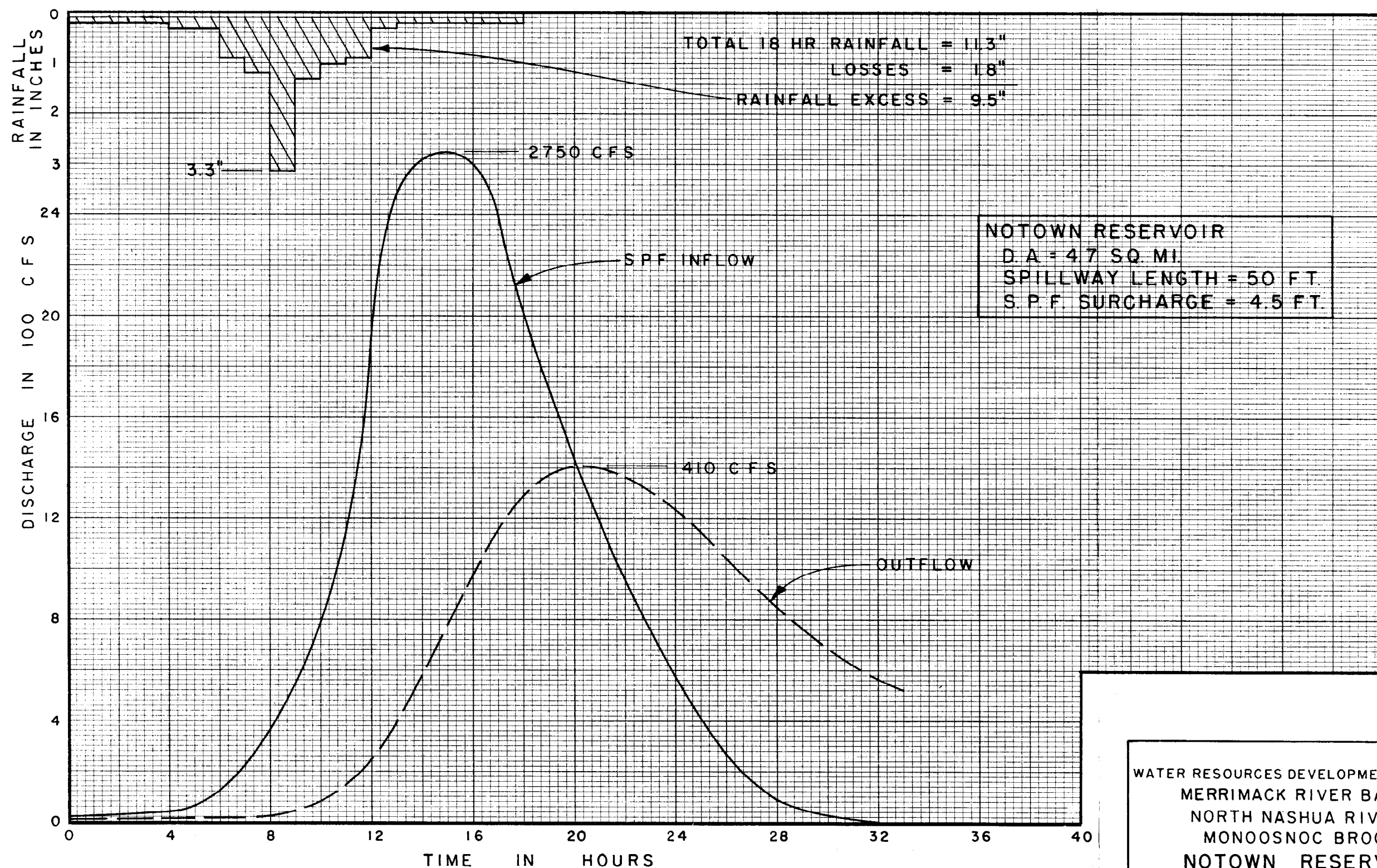
WATER RESOURCES DEVELOPMENT PROJECT

MERRIMACK RIVER BASIN  
 NORTH NASHUA RIVER  
 MONOOSNOC BROOK  
 DISCHARGE FREQUENCY

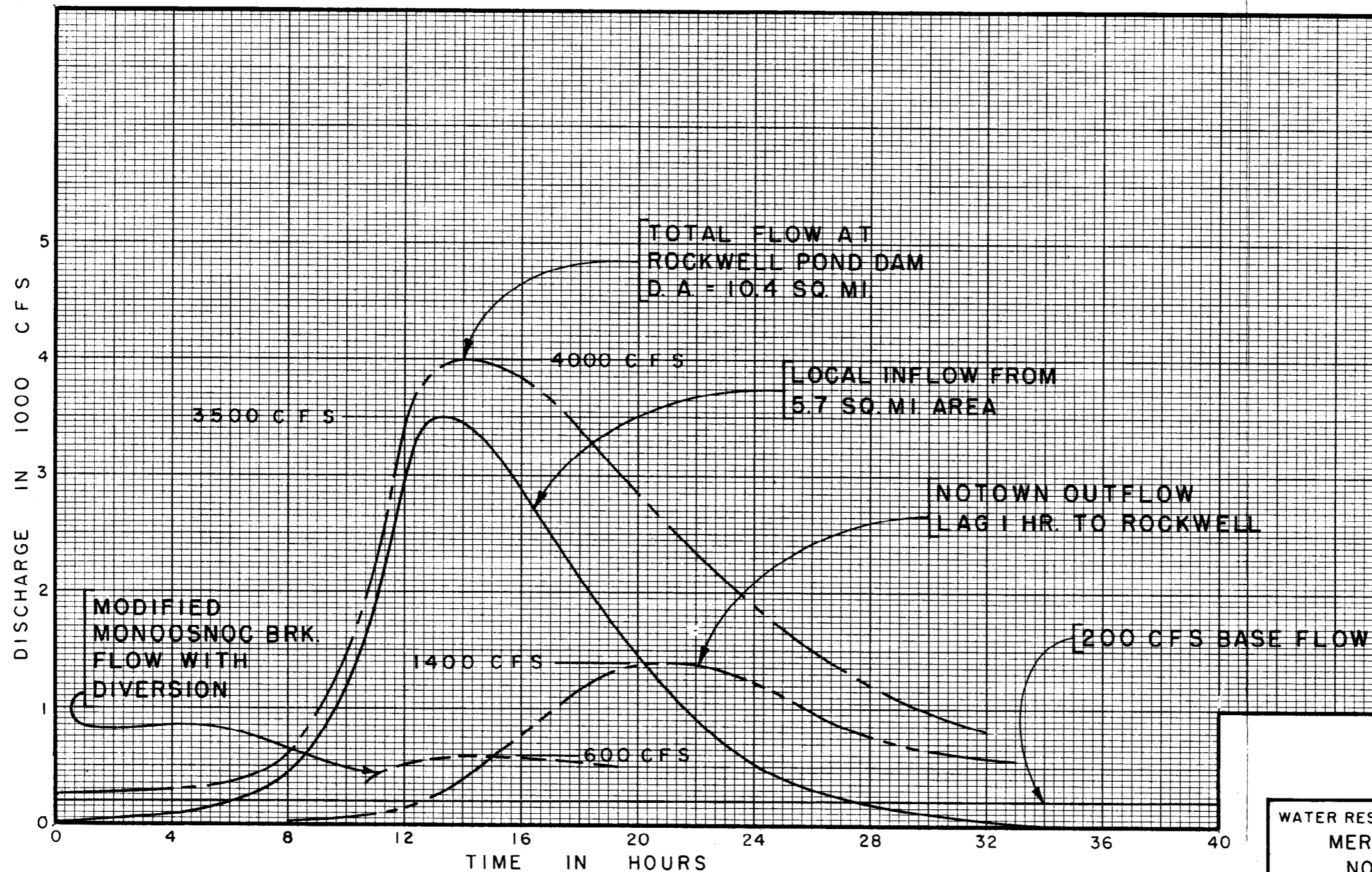
NEW ENGLAND DIVISION, WALTHAM, MASS.  
 OCTOBER 1976



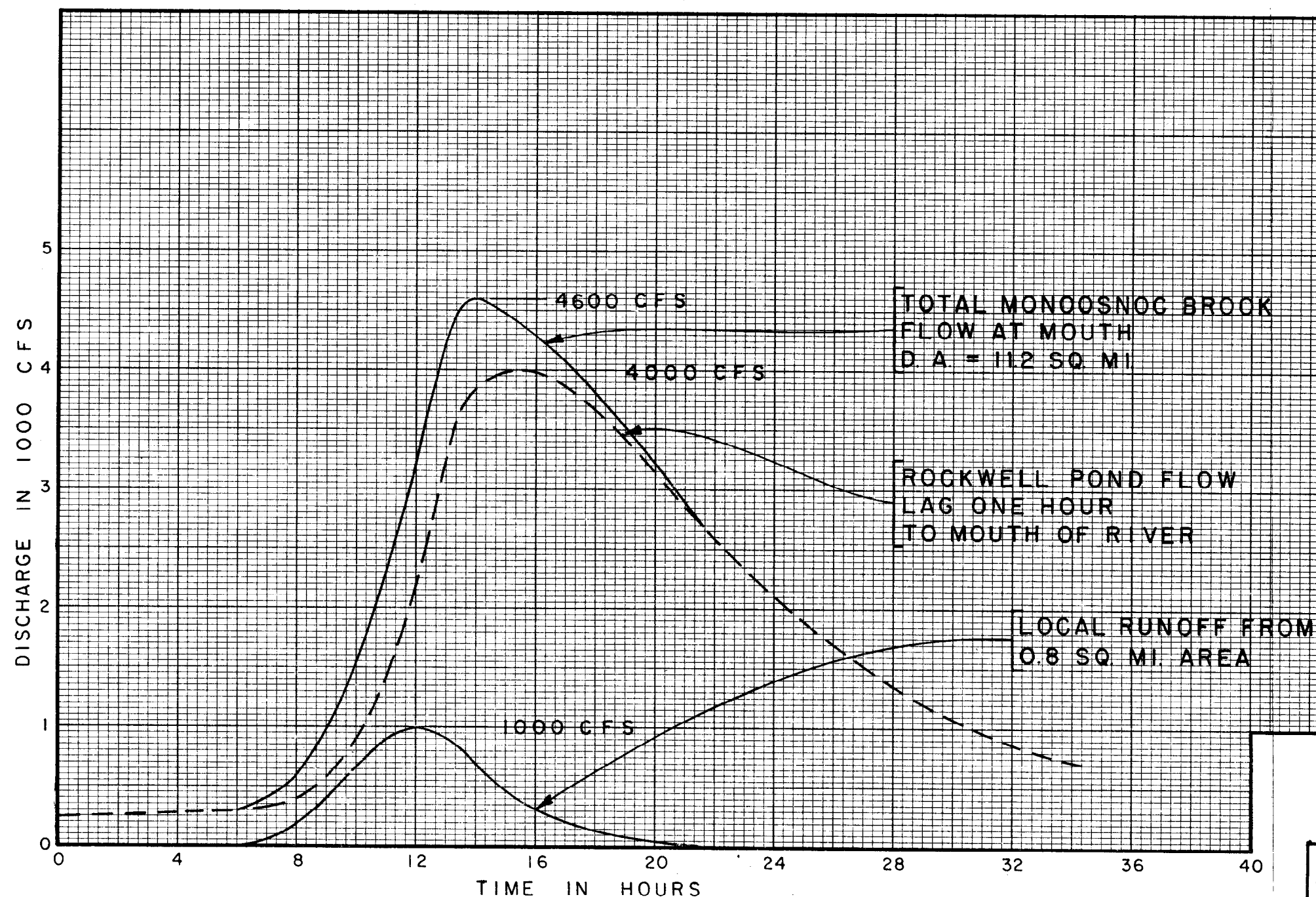
WATER RESOURCES DEVELOPMENT PROJECT  
 MERRIMACK RIVER BASIN  
 NORTH NASHUA RIVER  
 MONOOSNOC BROOK  
 BELOW NOTOWN RESERVOIR,  
 ONE HOUR UNIT-GRAPH  
 NEW ENGLAND DIVISION, WALTHAM, MASS.  
 OCTOBER 1976



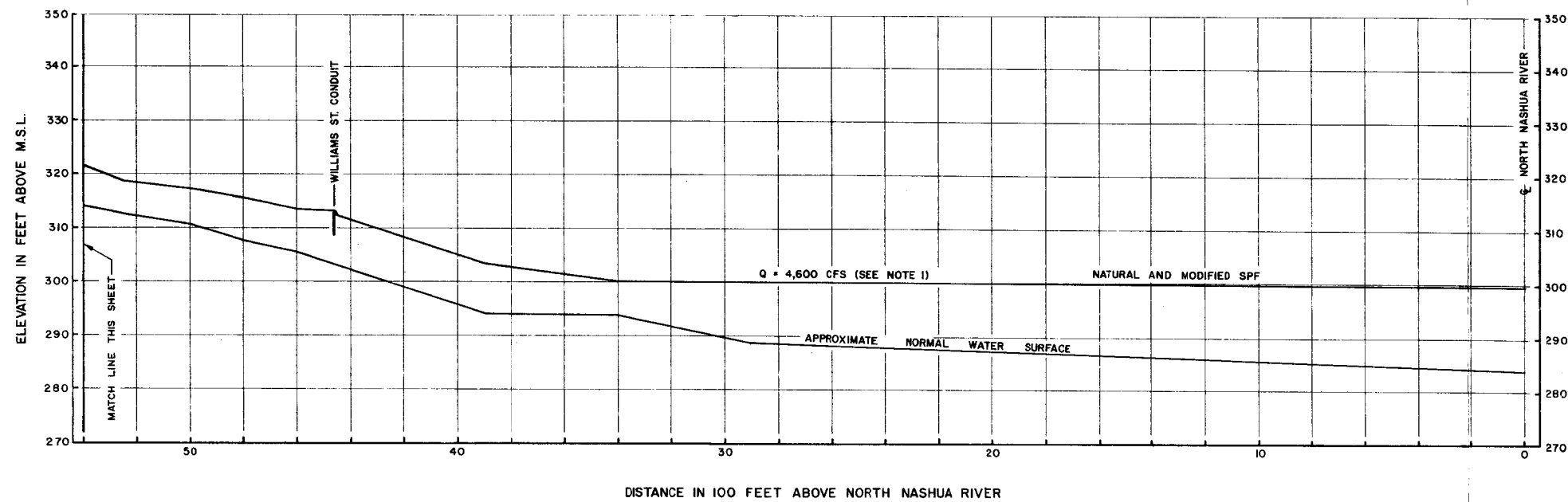
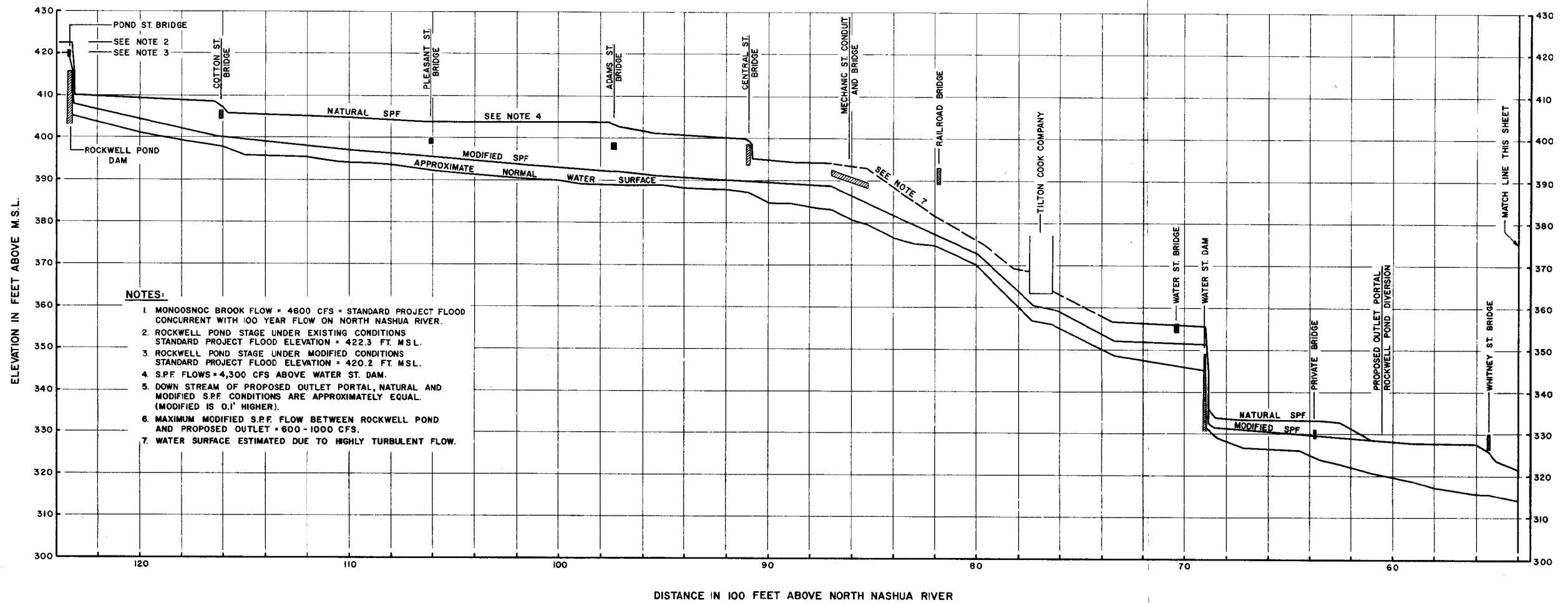
WATER RESOURCES DEVELOPMENT PROJECT  
MERRIMACK RIVER BASIN  
NORTH NASHUA RIVER  
MONOOSNOC BROOK  
NOTOWN RESERVOIR  
STANDARD PROJECT FLOOD  
NEW ENGLAND DIVISION, WALTHAM, MASS.  
OCTOBER 1976



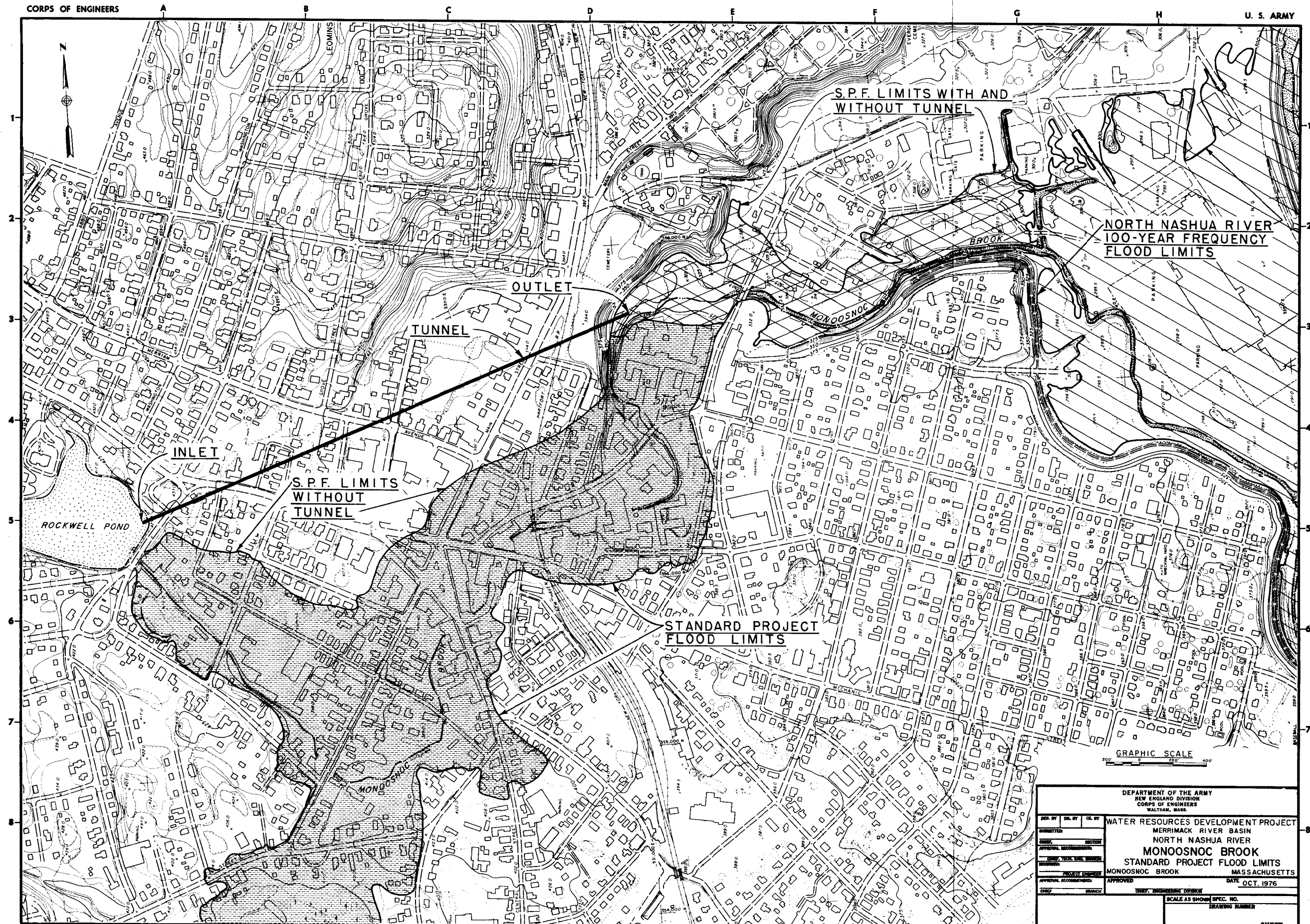
WATER RESOURCES DEVELOPMENT PROJECT  
 MERRIMACK RIVER BASIN  
 NORTH NASHUA RIVER  
 MONOOSNOC BROOK  
 ROCKWELL POND  
 STANDARD PROJECT FLOOD  
 HYDROGRAPHS  
 NEW ENGLAND DIVISION, WALTHAM, MASS.  
 OCTOBER 1976

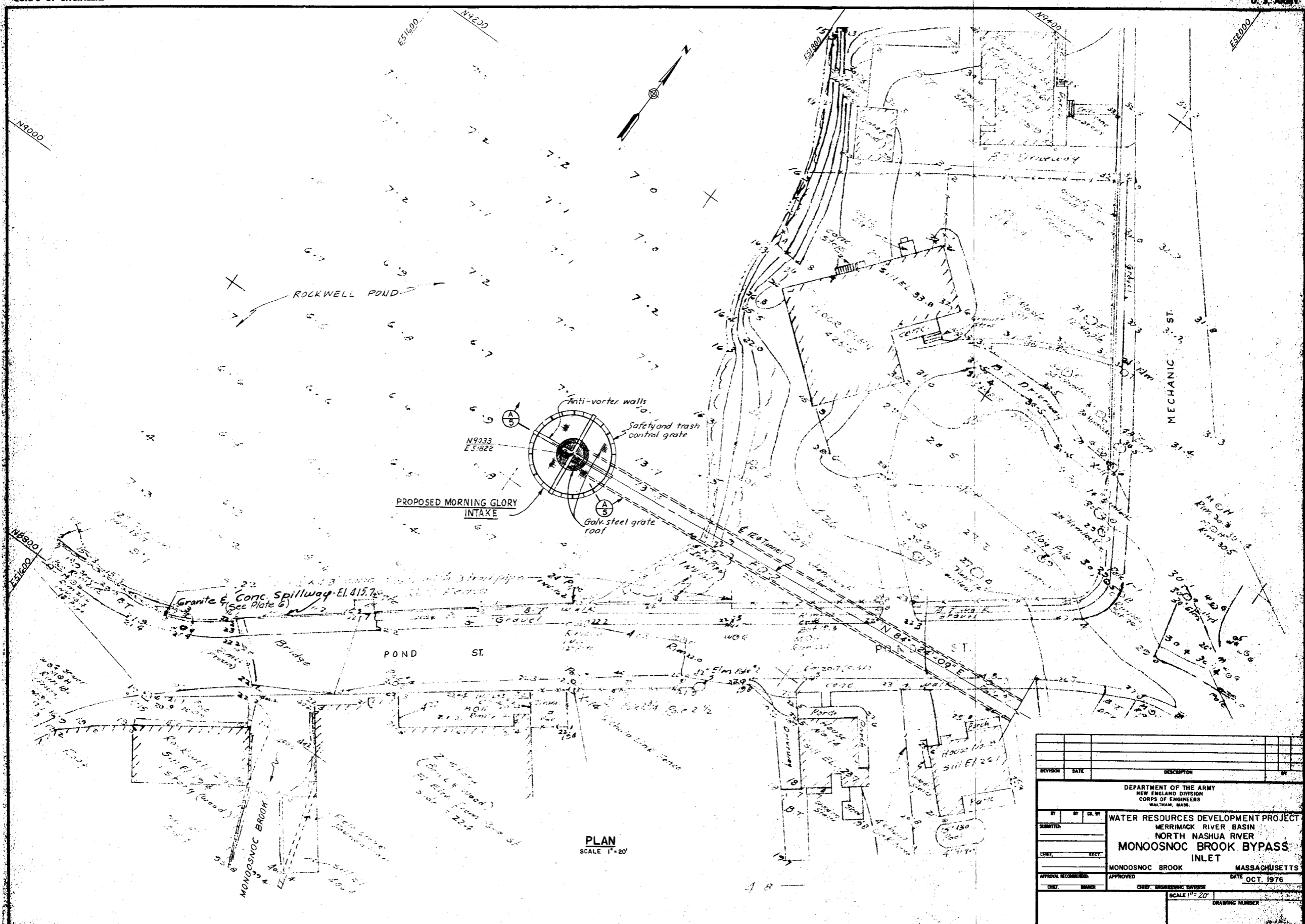


WATER RESOURCES DEVELOPMENT PROJECT  
 MERRIMACK RIVER BASIN  
 NORTH NASHUA RIVER  
 MONOOSNOC BROOK  
**STANDARD PROJECT FLOOD  
 HYDROGRAPHS**  
 NEW ENGLAND DIVISION, WALTHAM, MASS.  
 OCTOBER 1976



WATER RESOURCES DEVELOPMENT PROJECT  
 MERRIMACK RIVER BASIN  
 NORTH NASHUA RIVER  
 MONOOSNOC BROOK  
 FLOOD PROFILES  
 NEW ENGLAND DIVISION, WALTHAM, MASS.  
 OCTOBER 1976



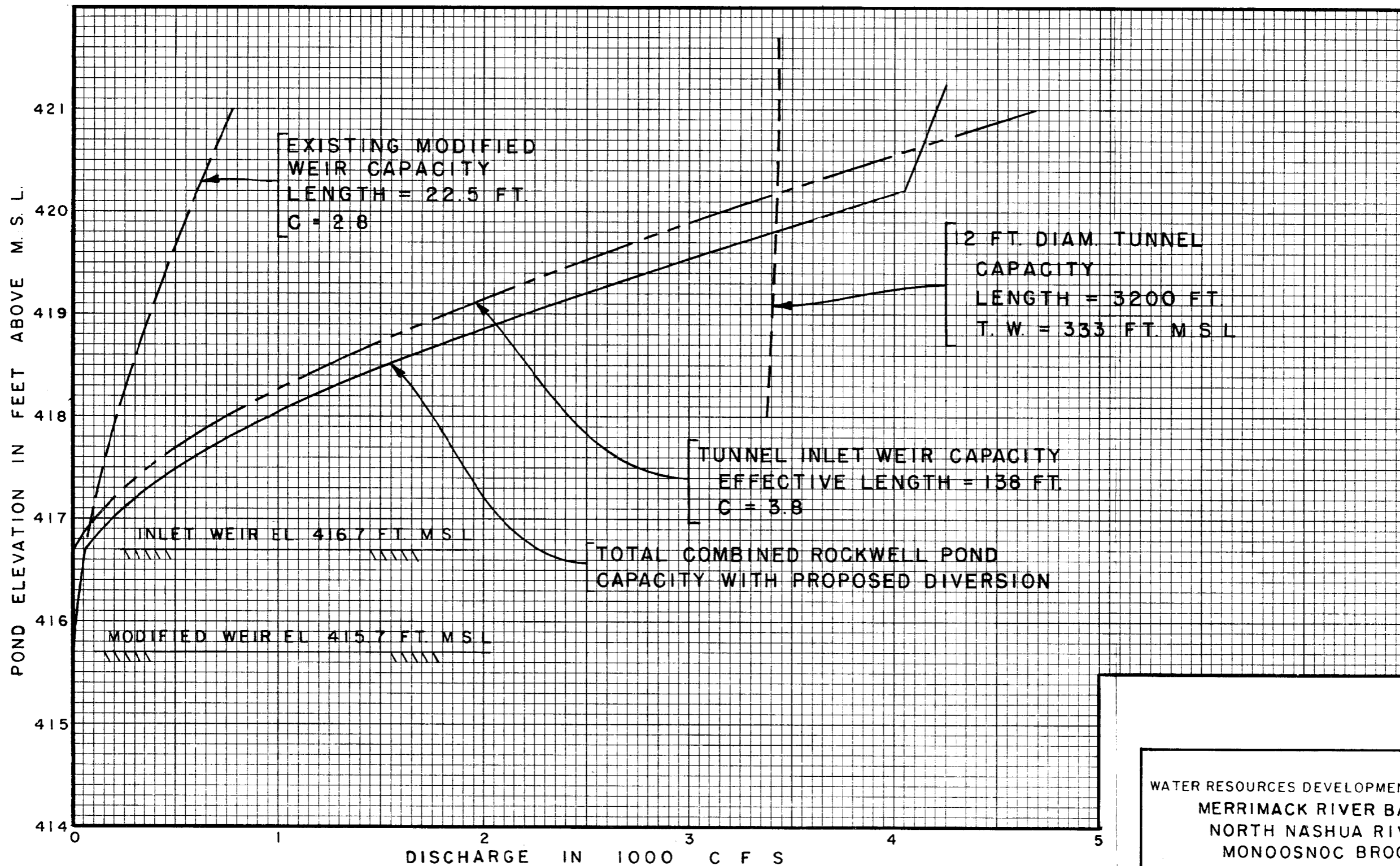


[illegible]



**GRAPHIC SCALE**

[illegible]



WATER RESOURCES DEVELOPMENT PROJECT  
 MERRIMACK RIVER BASIN  
 NORTH NASHUA RIVER  
 MONOOSNOC BROOK  
 ROCKWELL POND  
 RATING CURVES  
 NEW ENGLAND DIVISION, WALTHAM, MASS.  
 OCTOBER 1976